

Microcrystalline Germanium Carbide- A new material for PV conversion

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ABSTRACT

Microcrystalline Germanium-carbon alloy, c-(Ge,C):H, is an interesting new material with potential photovoltaic conversion applications. We will show in this paper that when one alloys C to Ge, the unique band structure of c-Ge appears to be retained, and a new direct gap material results. The preliminary results to date show that the material has a very high absorption coefficient, and that bandgaps in the range of 1.1 eV can be achieved. The material can be doped n and p type. We will report on the growth conditions and on material properties.

INTRODUCTION

It is well known that c-Ge is an almost direct gap material. Its lowest L valley in the conduction band is only about 0.16 eV below the central Γ valley, and as a result, c-Ge has a high absorption coefficient at energy values only about 0.16 eV above the thermal bandgap. This is in contrast to the case for c-Si, where the difference between the central valley and the lowest X valley is >2 eV. This is the reason why c-Si needs a thick layer to absorb most of the solar photons with energies greater than its thermal gap. Unfortunately, the bandgap of c-Ge is too low to be of interest for PV conversion.

Diamond is another Group IV semiconductor with a large indirect thermal gap (~ 5.4 eV). However, by alloying small amounts of C with Ge, it should be possible to shift the bandgap of the resultant alloy (Ge,C) up into the optimum solar range (~ 1.1 - 1.7 eV), and perhaps, maintain the favorable band structure of c-Ge. This material, $\text{Ge}_{1-x}\text{C}_x$, does not exist in nature. If one tries to make it from the melt, it phase separates. However, we have succeeded in making it by using a non-equilibrium process,

namely reactive plasma deposition in the presence of a strong flux of H. We call this material microcrystalline (Ge,C) alloy, denoted by c-(Ge,C):H. In this paper, we will report on the growth and the preliminary properties of this new material.

GROWTH TECHNIQUE

The material was grown using an ECR plasma reactor, operated in a remote plasma mode.[1]. The source gases were germane, methane and hydrogen. The substrate temperature was in the range of 300-350 C. The hydrogen dilution ratio was very high ($>50:1$). The growth pressure was in the range of 5 mT. Films were deposited on 7059 glass, and on stainless steel substrates. It was found that the crystallinity was improved when the films were deposited on stainless steel.

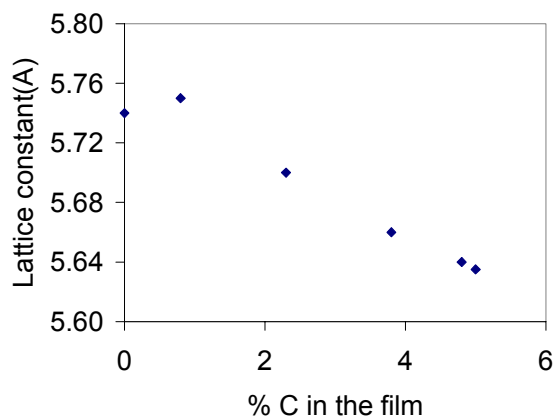


Fig. 1 Lattice constant of films as a function of C content.

MATERIAL MEASUREMENTS

The crystallinity of the material was checked using x ray diffraction and Raman spectroscopy. In Fig. 1, we show the lattice constant determined from x-ray measurements. The grain size of the films, determined from Scherer's formula, was in the range of ~ 50 nm.

In Fig.2, we show the absorption coefficient of the film, determined using a spectro-photometer. Quite clearly, as the c-(Ge,C):H film has bandgap higher than that of c-Ge, but the absorption curve seems to shift linearly in energy as C is added. This results implies that the favorable band structure of Ge is maintained as small amounts of C are added to it. This is a very encouraging preliminary result.

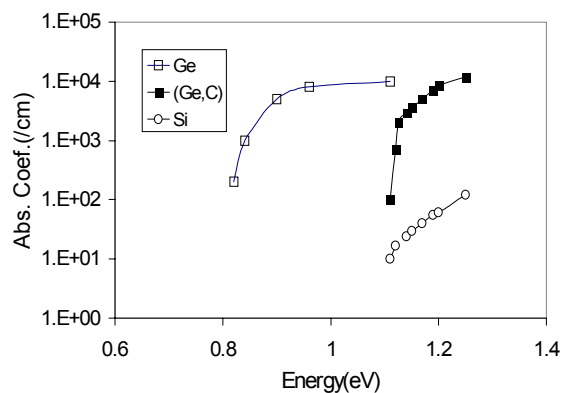


Fig. 2 Absorption coefficients of c-Ge, c-Si and c-(Ge,C):H films

The films could be doped both p and n type using phosphine as the n type dopant gas and diborane as the p type dopant gas.. In Fig. 3, we show the conductivity of the films as a function of flow of phosphine or diborane.

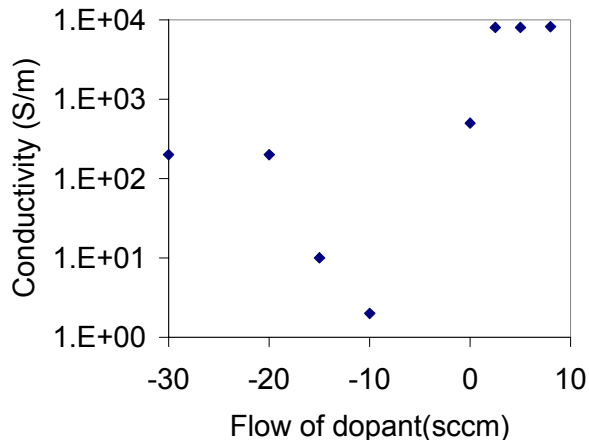


Fig. 3 Conductivity of n and p type doped films as a function of phosphine(positive flow) and diborane (negative flow) values

CONCLUSIONS

In summary, we have shown that it is possible to bond C to Ge in a crystalline lattice by using a low temperature growth process. The use of a hydrogen rich plasma is particularly useful because H bonds to grain boundaries and passivates them, a situation similar to that of microcrystalline Si made with a hydrogen plasma. We have been able to bond 4-5% C into Ge, and the resulting bandgap is close to that of Si. The low C content (Ge,C) alloy shows an absorption curve which is similar in shape to that of c-Ge, and has a much higher absorption than that of Si at comparable wavelengths. The material can be doped both p and n type using appropriate dopant gases. All these results indicate that this material may be suitable for photovoltaic energy conversion.

ACKNOWLEDGEMENT

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REFERENCES

1. Jason Herrold and Vikram Dalal, J. Non-Cryst. Solids, J.Non-Cryst. Solids., 270, 255(2000)